Modification of the shielded beam screen design & misalignment analysis

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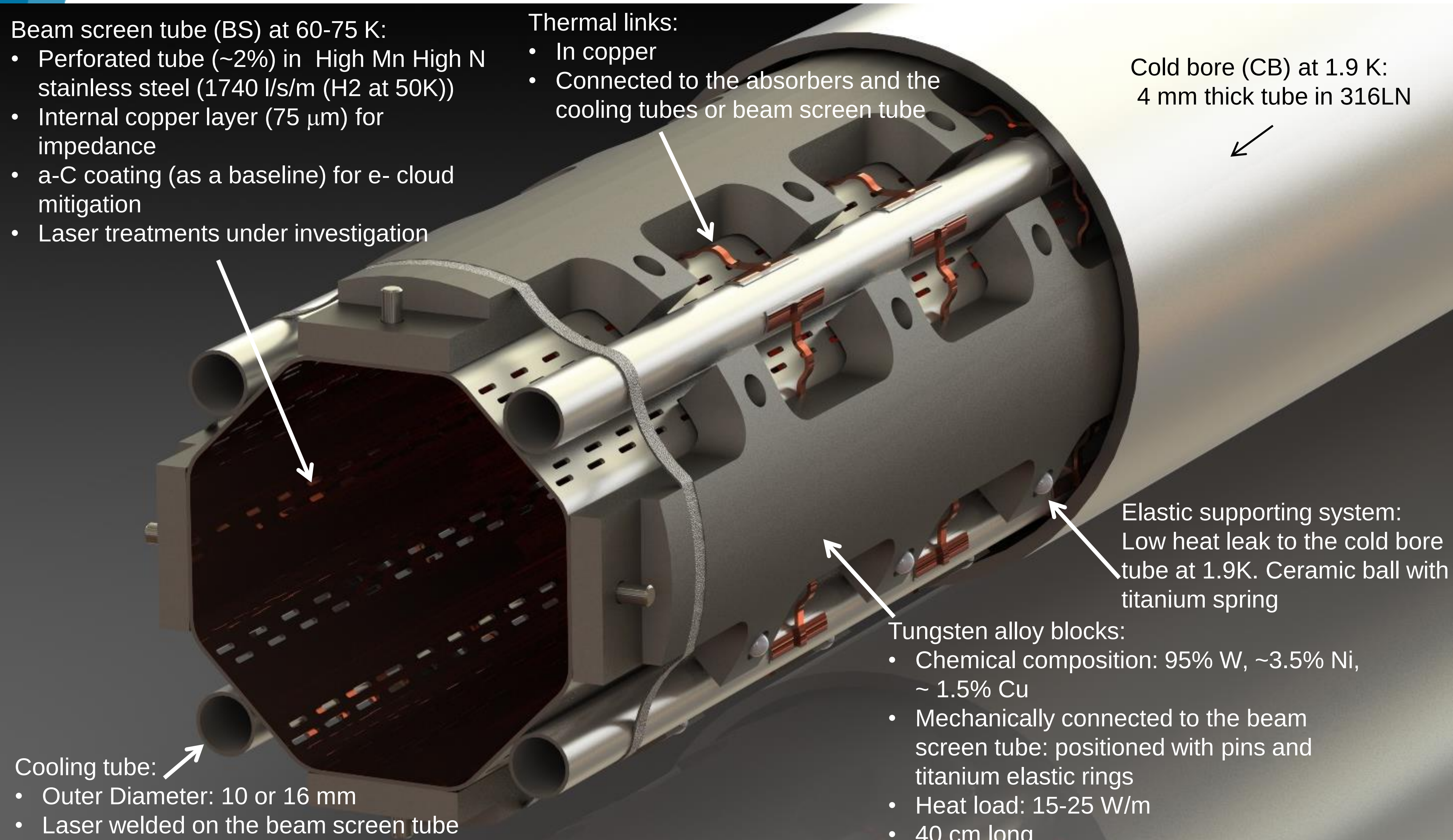
HL-LHC TCC, 8th March 2018

Outline

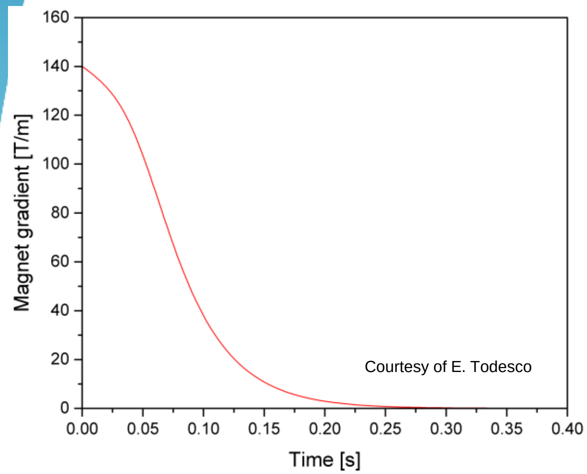
- Concept
- Behaviour during quench
- Main modifications of the beam screens due to CLIQ
- Misalignment effects of the beam screen in the cold bore
- Conclusions

Concept

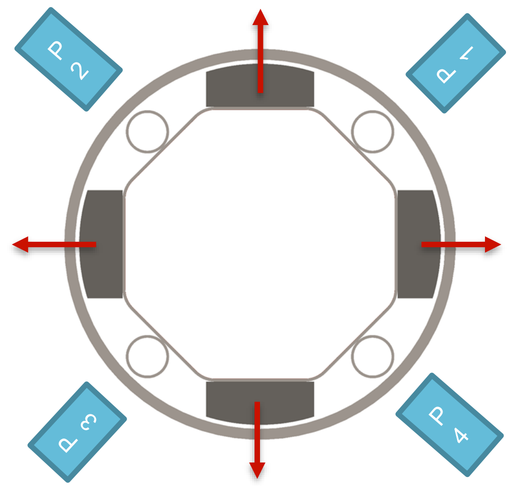

Beam screen tube (BS) at 60-75 K:
• Perforated tube (~2%) in High Mn High N stainless steel (1740 l/s/m (H2 at 50K))
• Internal copper layer (75 μm) for impedance
• a-C coating (as a baseline) for e- cloud mitigation
• Laser treatments under investigation
Thermal links:
• In copper
• Connected to the absorbers and the cooling tubes or beam screen tube
Cold bore (CB) at 1.9 K:
4 mm thick tube in 316LN
Elastic supporting system:
Low heat leak to the cold bore tube at 1.9K. Ceramic ball with titanium spring
Tungsten alloy blocks:
• Chemical composition: 95% W, ~3.5% Ni, ~ 1.5% Cu
• Mechanically connected to the beam screen tube: positioned with pins and titanium elastic rings
• Heat load: 15-25 W/m
• 40 cm long
Cooling tube:
• Outer Diameter: 10 or 16 mm
• Laser welded on the beam screen tube

Behaviour during a magnet quench

Quench heaters vs CLIQ



Magnet gradient decay with quench heaters

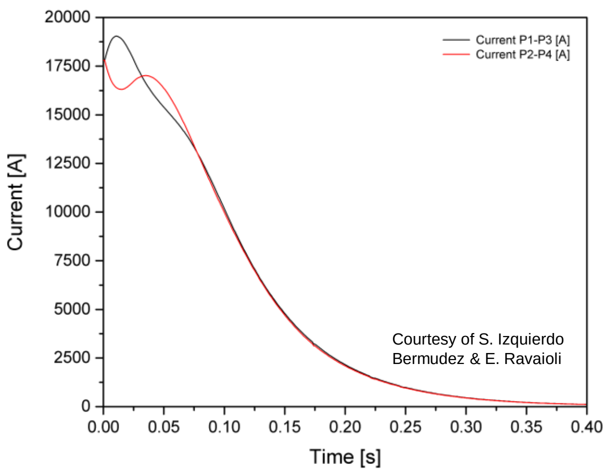


Expected forces in red

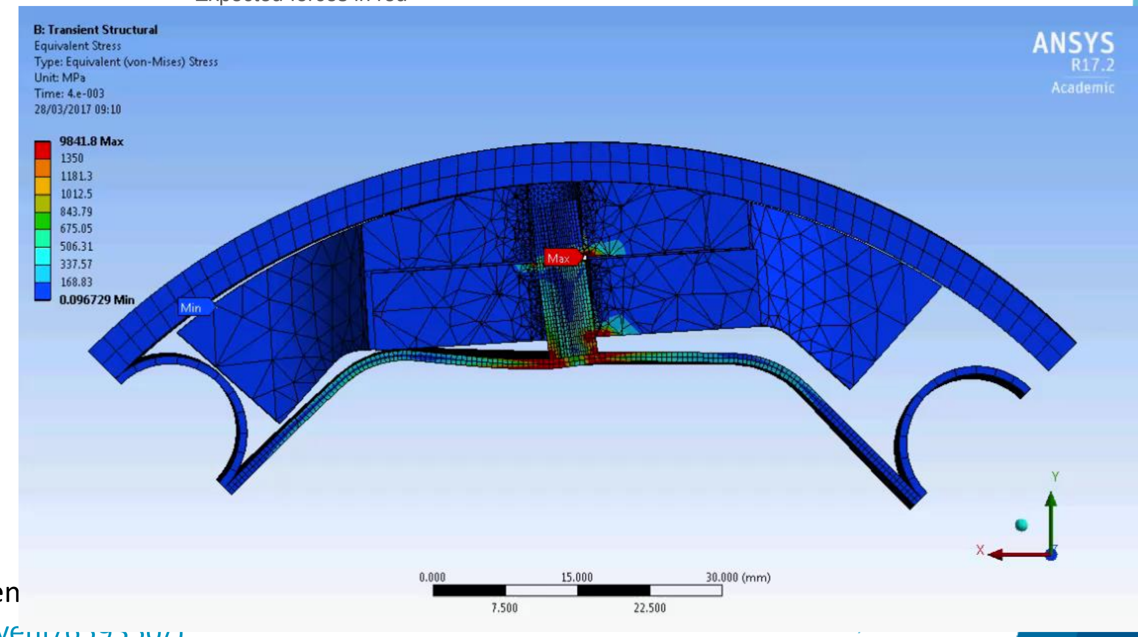
Specific Lorentz forces reads:

$$f \propto \frac{G\dot{G}}{\rho} r^3$$

- → Lorentz forces driven by GG' product
- → Lorentz forces acting on the beam screen are pointing toward the cold bore
- → Lorentz forces are maximum after 50 ÷ 60 ms.



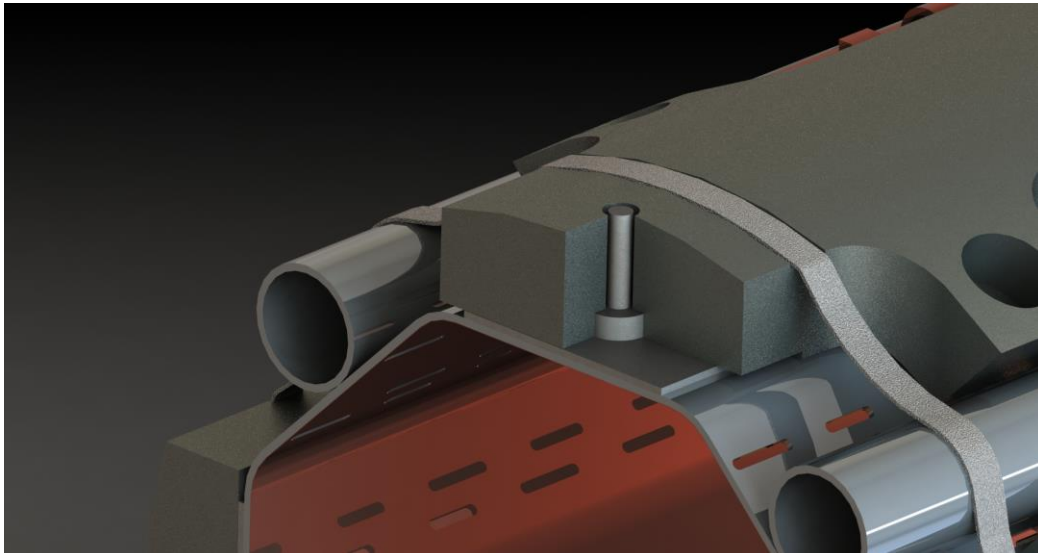
Current decay with CLIQ discharge



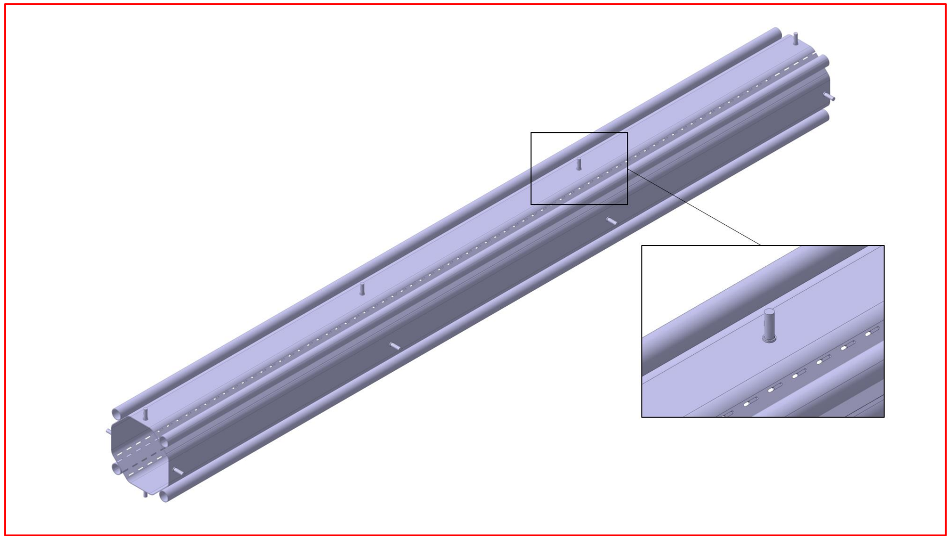
The study has been presen

(https://indico.cern.ch/even

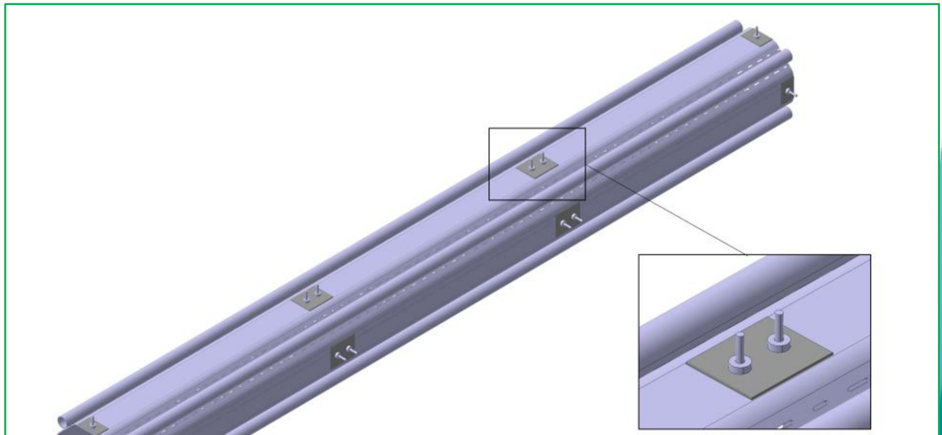
Main modifications of the Q1 beam screen



Old design

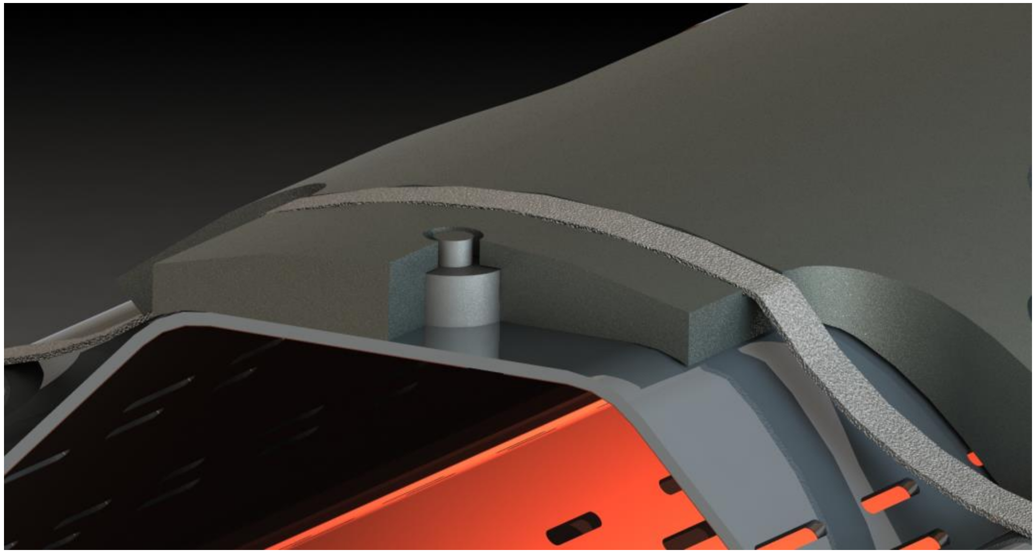


New design

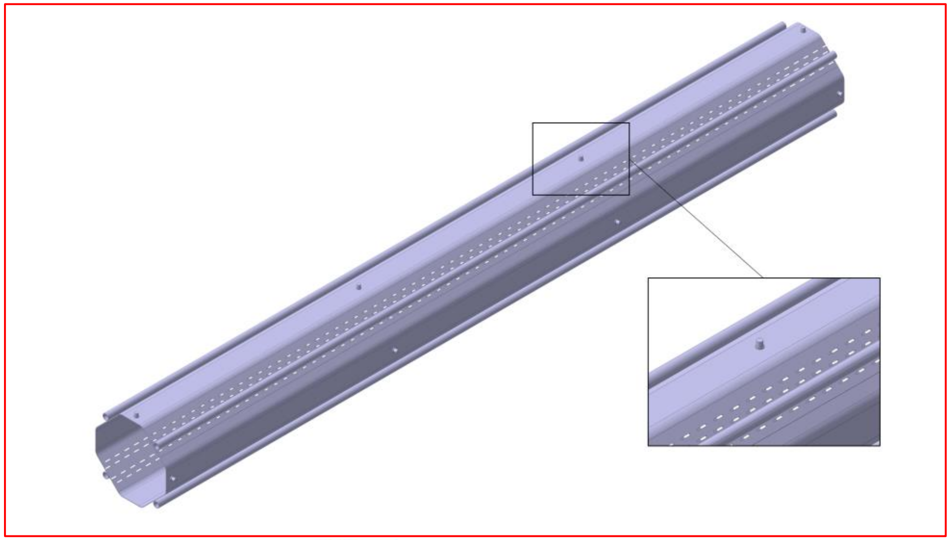


New pin (2 per W block) + reinforcement plates

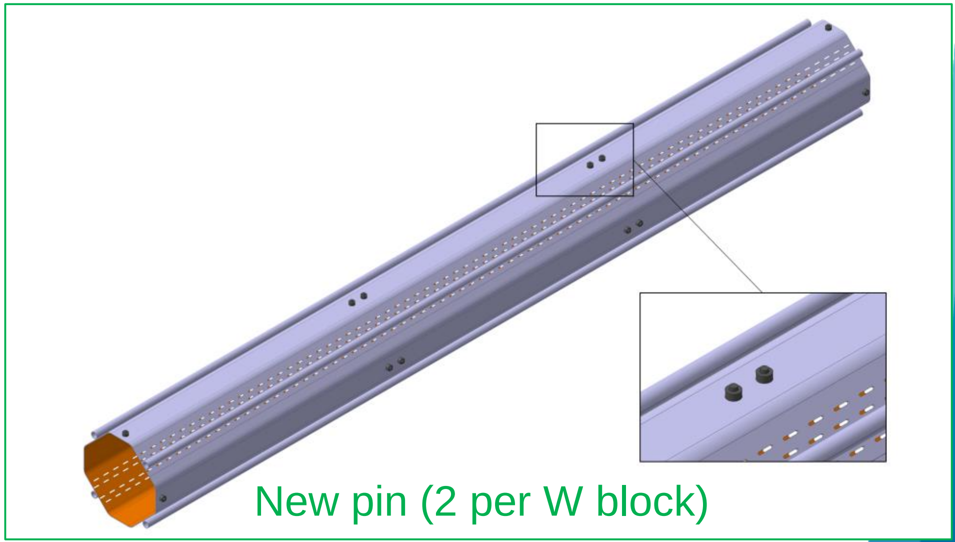
Main modifications of the Q2x-Q3-D1 beam screens



Old design

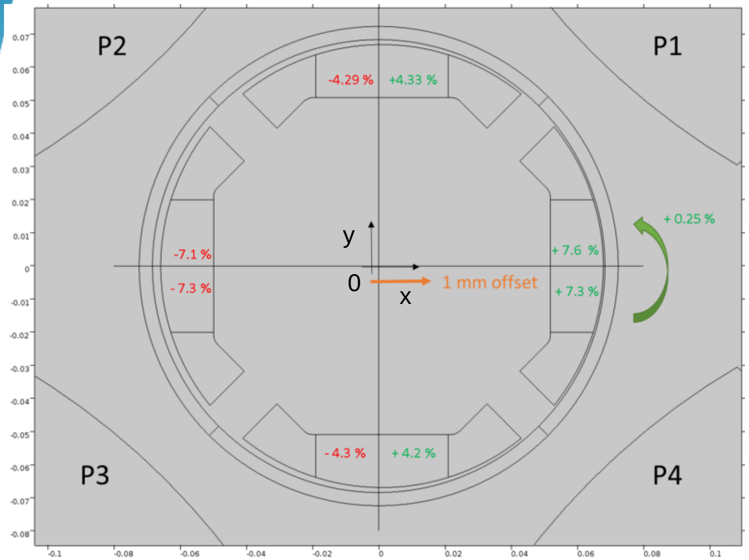


New design

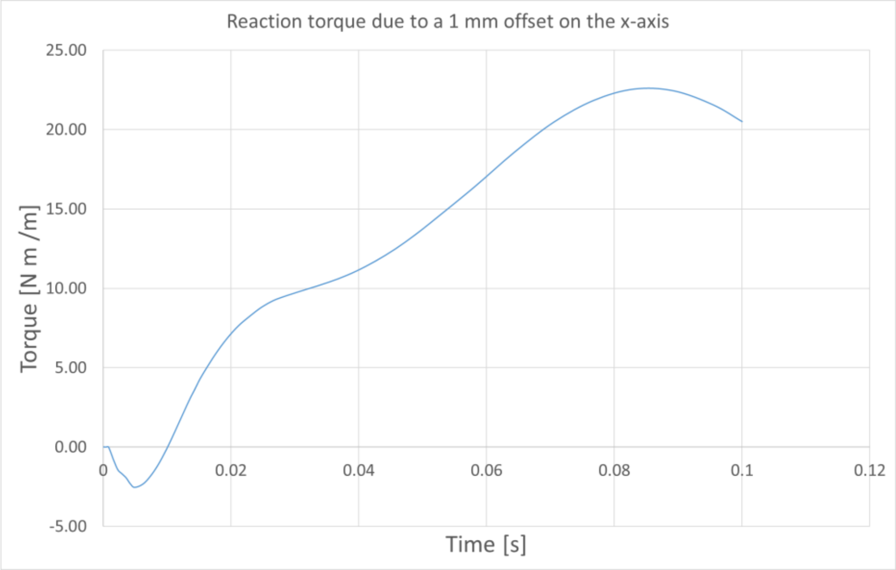


Misalignment effects of the beam screen in the cold bore

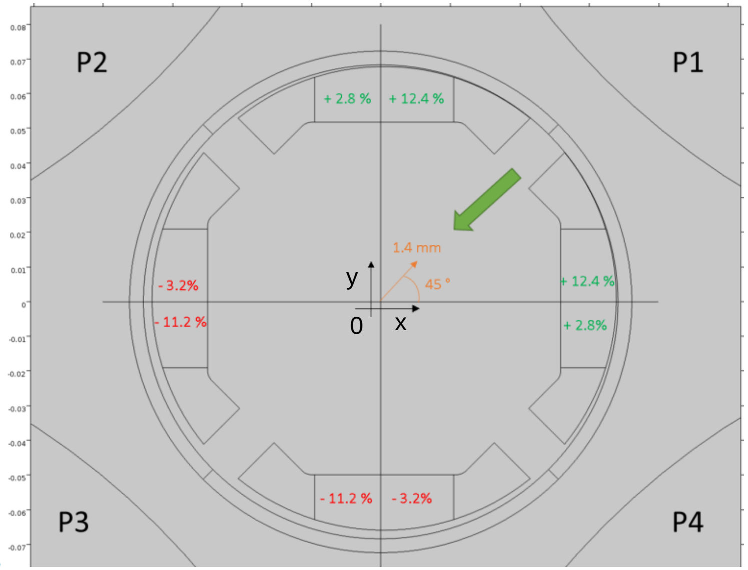
@ 5 ms



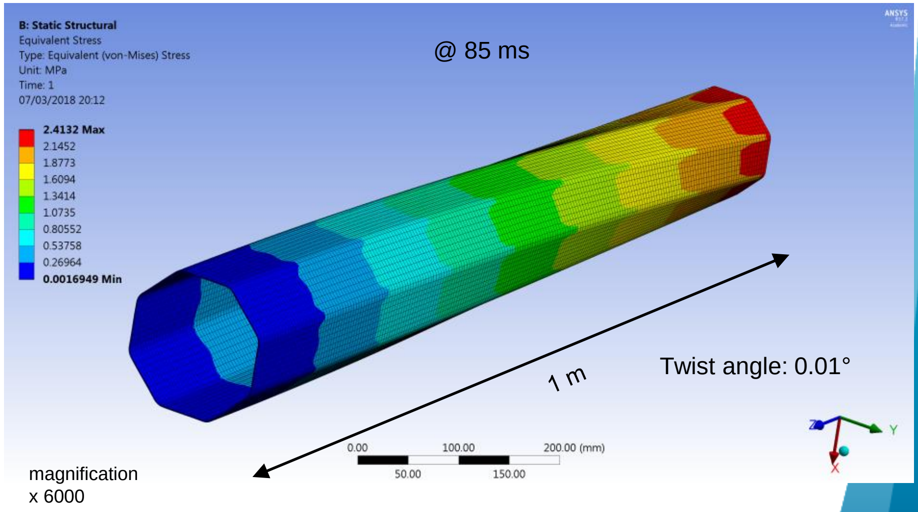
Variation of the forces in the W blocks due to 1 mm offset on the x-axis of the BS in comparison with the nominal case at 5 ms.



Reaction torque of the BS fixed at one end during the CLIQ discharge



Variation of the forces in the W blocks due to 1.4 mm offset at 45 ° of the BS in comparison with the nominal case at 5 ms.



Maximum V.M. stress on the fixed end of the BS due to the 1 mm offset .

The misalignment effects are negligible at the fixed point of the beam screen.

Conclusions

- The cost estimate for the beam screen modification is 250 kCHF, which includes:
  - raw material;
  - machining and assembly of additional pins;
  - reinforcement plates;
  - elastic rings;
  - drawing updates.

- No impact neither on schedule nor on the performance is expected:
  - no impact on aperture;
  - no impact on field quality;
  - non significant impact on shielding efficiency.

- No impact on the beam screen fixed point due to a misalignment of the beam screen in the cold bore.

EDMS NO.	REV.	VALIDITY
1893675	0.1	DRAFT

REFERENCE : LHC-VSM-EC-0001

HL – LHC Engineering Change Request
Modification of the shielded beam screen design

ECR DESCRIPTION

WP Originator	WP12, PBS 12.1.1	*Process*	Engineering
Equipment	LHCVSM	*Baseline affected*	Cost
Drawing	N/A	*Date of Issue*	2018-01-07
Document	N/A	*CI responsible*	C. Garion
WPs Affected	WP12	*Reference Document*	TDR Version 0.1

Detailed Description

New beam screens with tungsten based alloy shielding will be installed in the HL-LHC triplet areas. The design of these beam screens is based on an octagonal perforated tube made of 1 mm stainless steel with a 75 µm copper layer on the inner side. Absorbers, 16 mm and 6 mm thick for the Q1 and Q2a to D1, respectively, are 40 cm blocks positioned on the beam tube thanks to stainless steel pins. To minimize the amount of pins, an overlap of two consecutive blocks is applied. The heat deposited on the tungsten absorbers is transferred to the cryogenic cooling tubes by copper thermal links (Fig. 1).

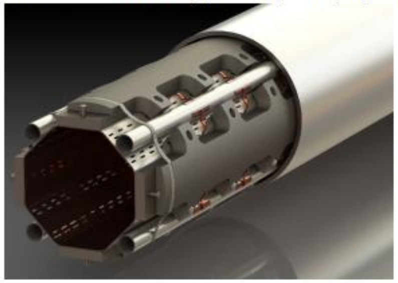


Fig. 1 HL-LHC shielded beam screen

The design of these beam screens shall be compatible with magnet quenches (EDMS 1361079). During fast magnetic field decay, eddy currents and consequently Lorentz forces are induced in the conductive parts of the beam screen in particular in the copper layer and the tungsten absorbers. In case of monotonic field decay, as produced by quench heaters, Lorentz forces acting on the beam screen are pointing toward the cold bore. For example, for the Q1 quadrupole, forces per quadrant of 37 N/m and 230 N/m are expected in the copper layer and tungsten absorbers. During the quench, the beam screen is elastically deformed, the tungsten blocks leans on the cold bore and most of the Lorentz forces induced in the tungsten absorbers is transferred to the 4 mm thick stainless steel tube.

Reasons for change

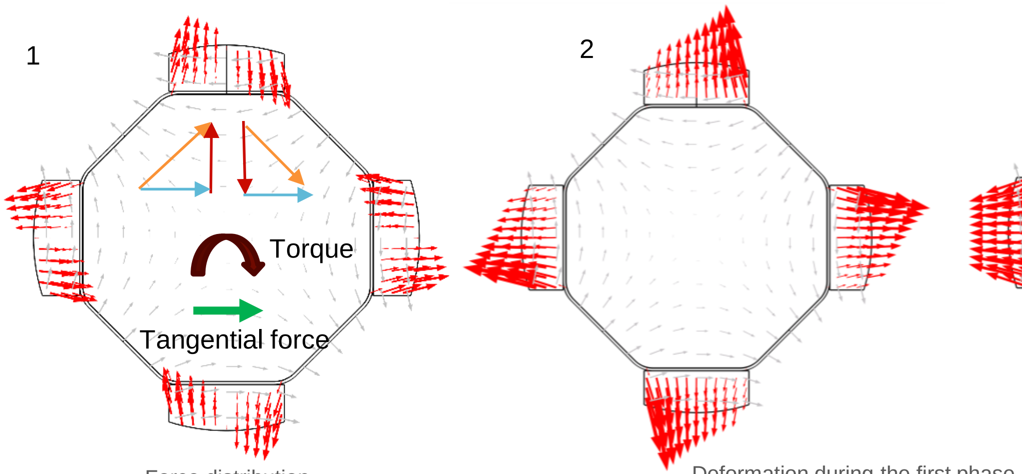
A new quench protection system, called CLIQ [1], has been proposed for the triplet quadrupoles. It is based on a fast transient alternative current unbalanced between the different coils of the magnet. This fast alternative current induces dissipation and temperature increase in the superconductor and then leads to the resistive transition. The fact that the current evolution is not anymore monotonic leads to an inversion of the Lorentz force direction (forces pointing toward the aperture center for a current increase). In addition, during this transient, the current evolution is different in two adjacent coils: one is subjected to a current decay leading to forces pointing to the cold bore whereas a current increase occurs in the other one leading to forces toward the aperture center. For the beam screen and in particular for the tungsten blocks, this leads to torques of 700 N.m and 580 N.m, per beam screen meter, for the absorbers and beam screen tube, respectively (Fig. 2). In case of magnet quench with the CLIQ protection system, the pins are not anymore only positioning elements but are structural components subjected to mechanical forces and torques. The design of the beam screen with positioning pins is not compatible with the CLIQ discharge (high stresses and plastic deformation in the pin areas).

Thank you for your attention

Backup slides

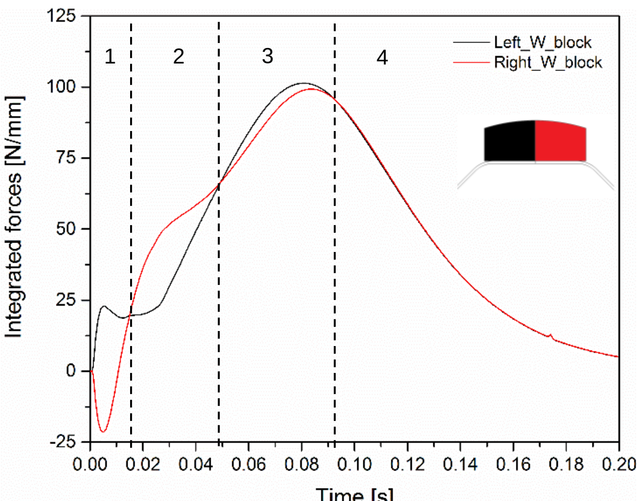
Behaviour during a magnet quench

Impact of CLIQ



Force distribution

Deformation during the first phase



Integrated forces induced in half W block

Phase 1: Most critical!!

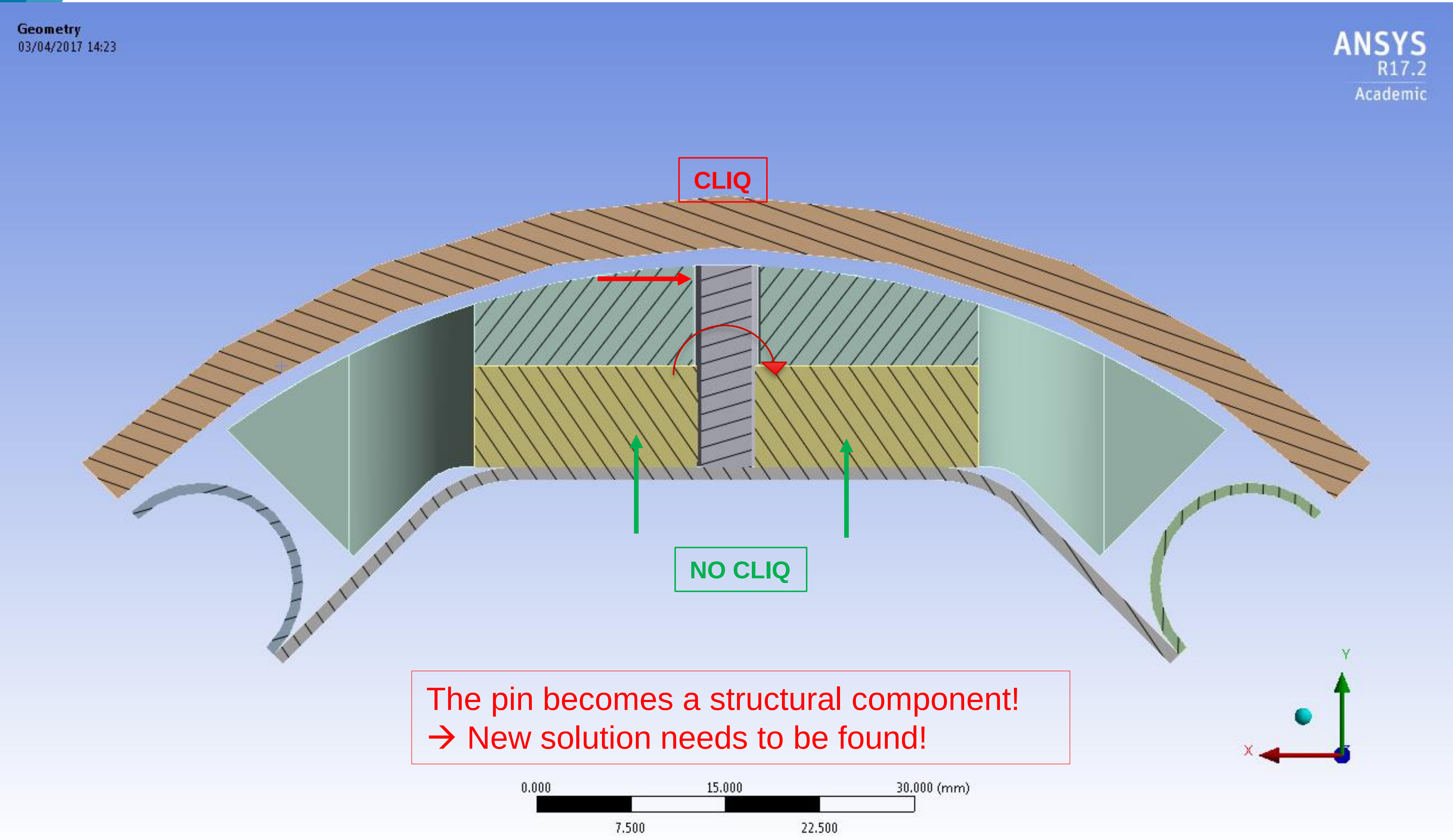
component	Q1		Q2	
	Torque [N m/W block]	Tangential force [N/W block]	Torque [N m/W block]	Tangential force [N/ W block]
Cold bore	250	3400	250	3400
Heat absorber	280	4200	150	2200
Octagonal pipe	80	1600	230	3800

Phase 2: Less severe than phase 1

Phase 4: Less severe than without CLIQ

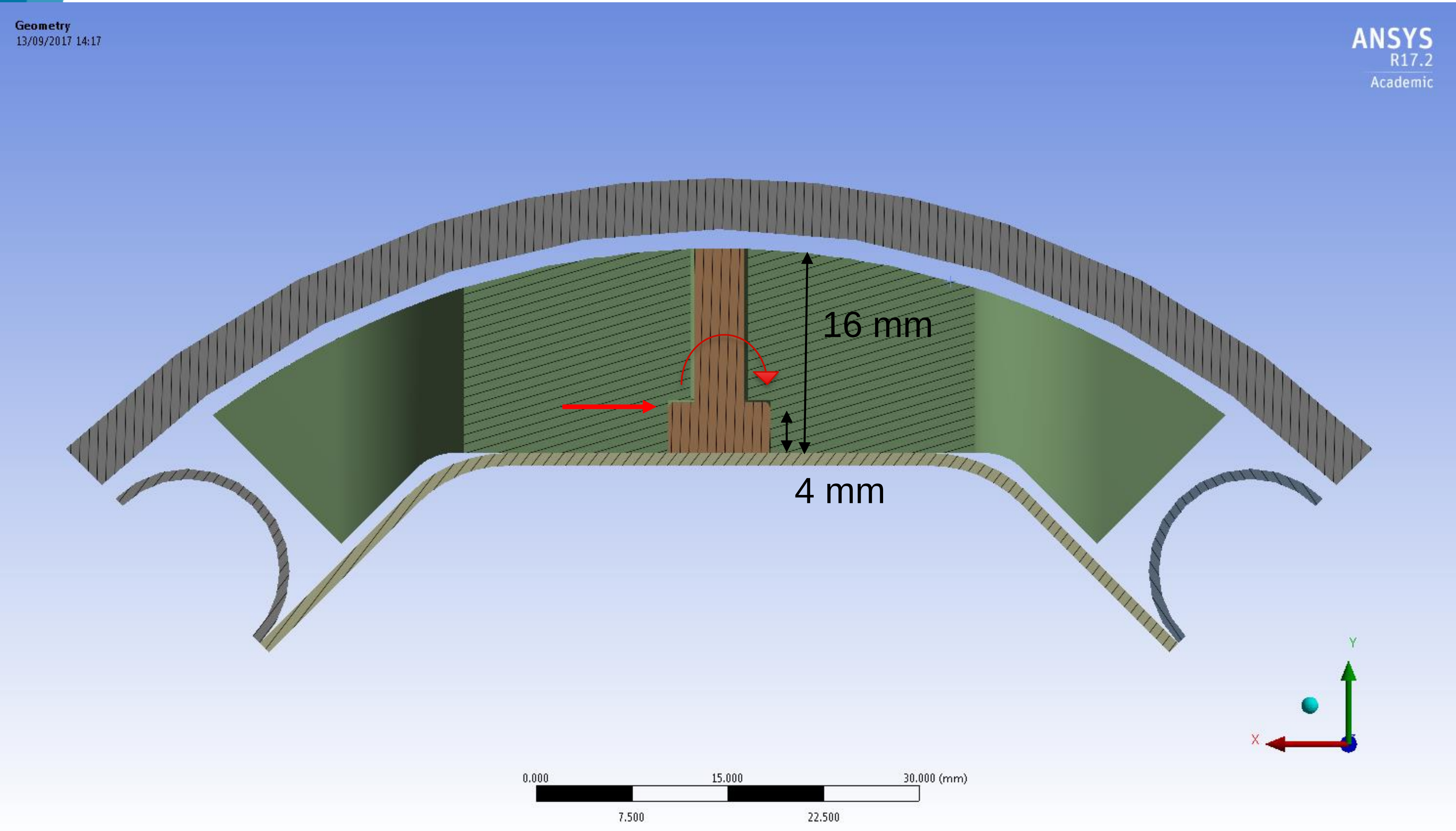
E.g. Fy for the tungsten block: $Q1_{NO\ CLIQ}$ ~230 [N/mm] > $Q1_{CLIQ}$ ~200 [N/mm]

Impact of CLIQ

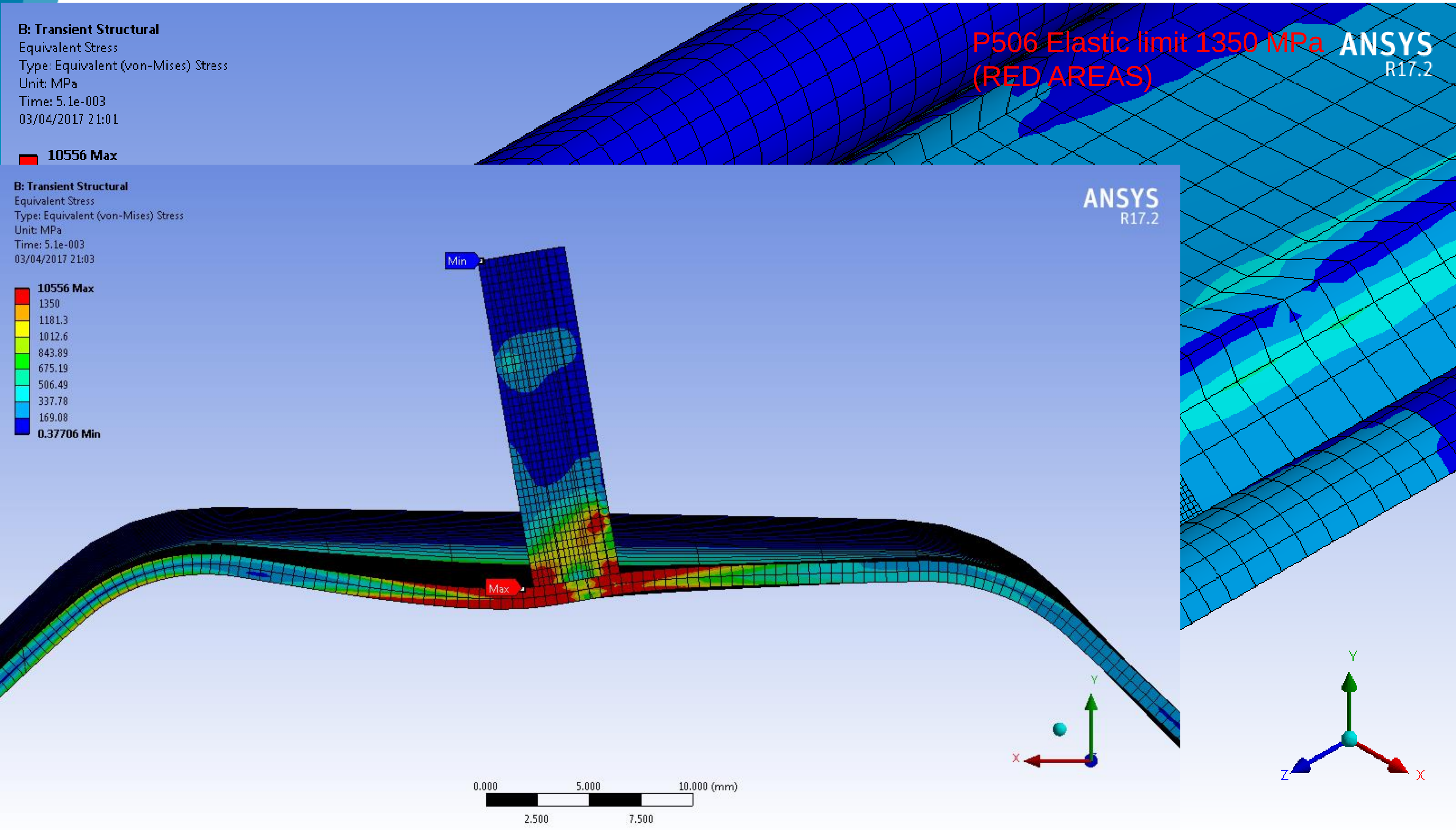


The pin becomes a structural component!
→ New solution needs to be found!

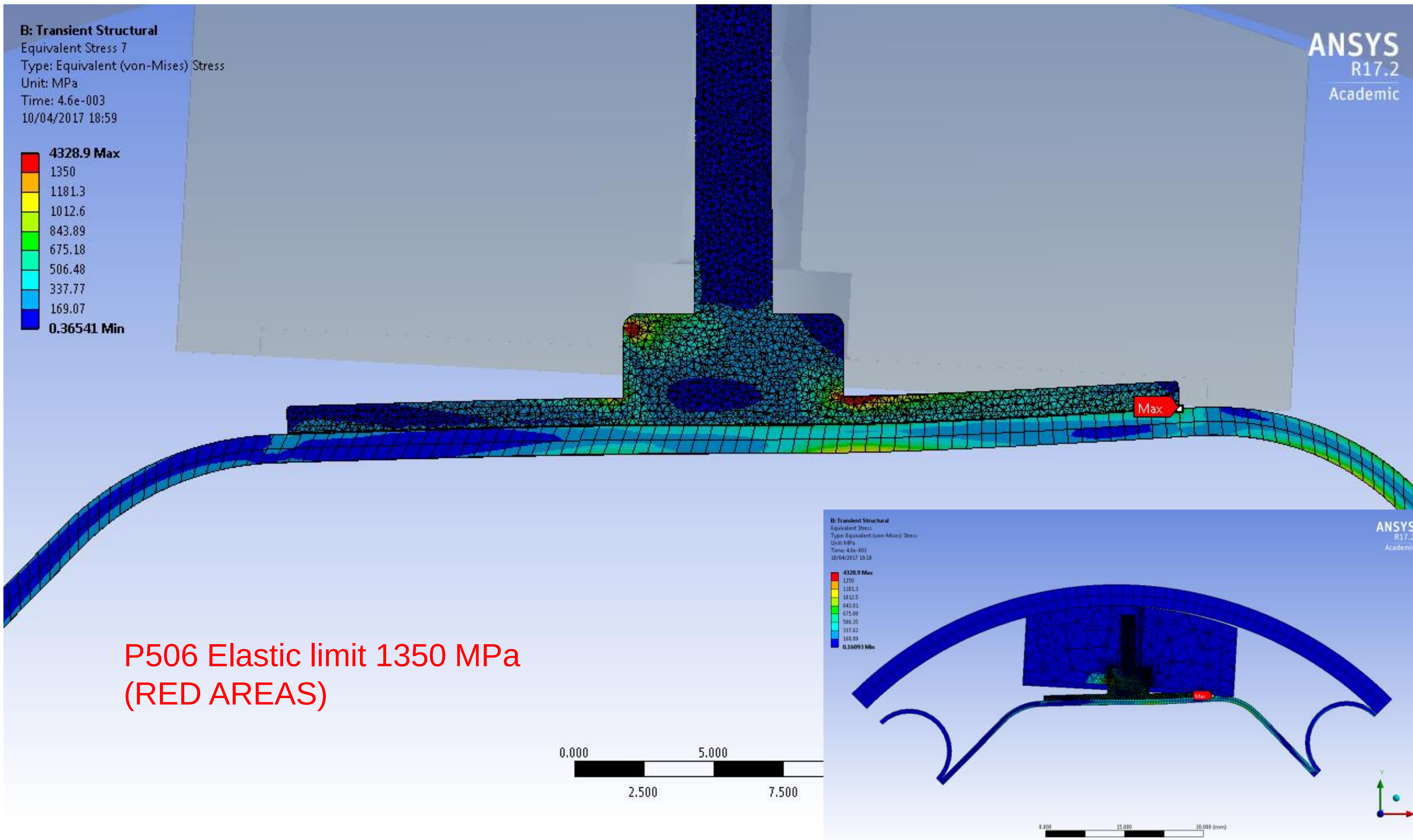
Proposed solution



Q1 beam screen during the CLIQ discharge

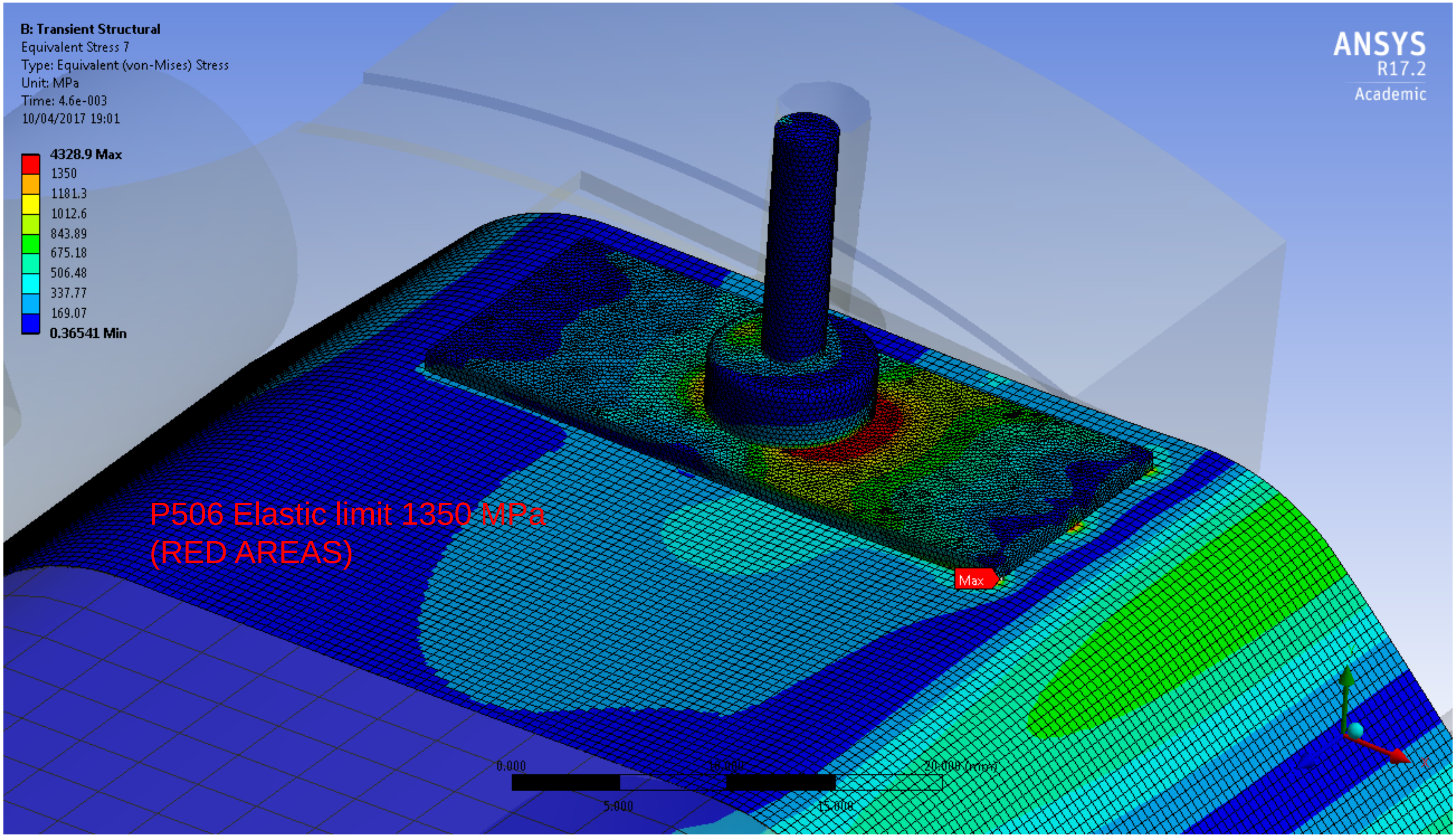


Proposed Q1 beam screen during the CLIQ discharge_v2



P506 Elastic limit 1350 MPa
(RED AREAS)

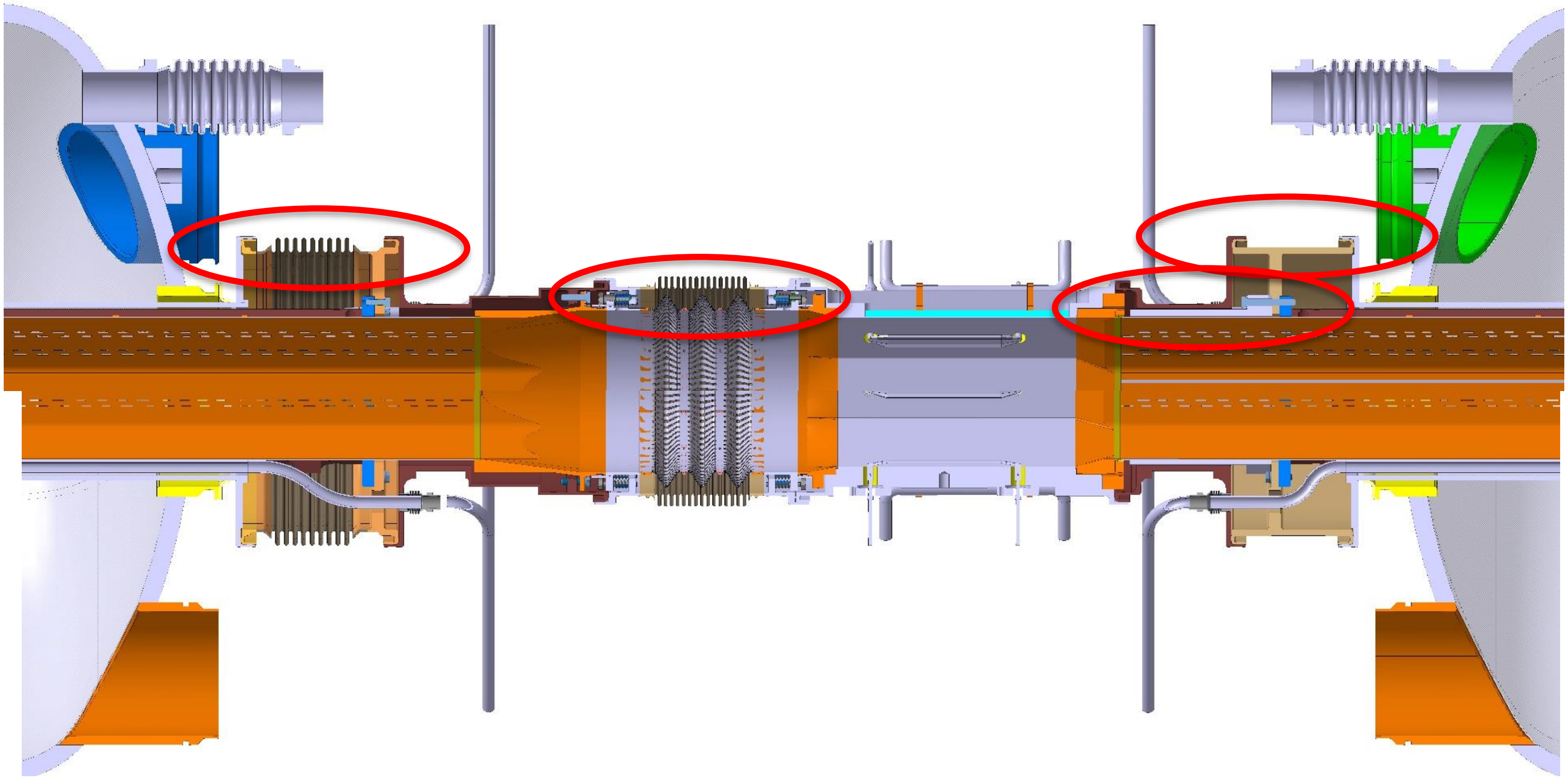
Proposed Q1 beam screen during the CLIQ discharge_v2



Beam screen extremities and interconnections

Layout

0/90° cut



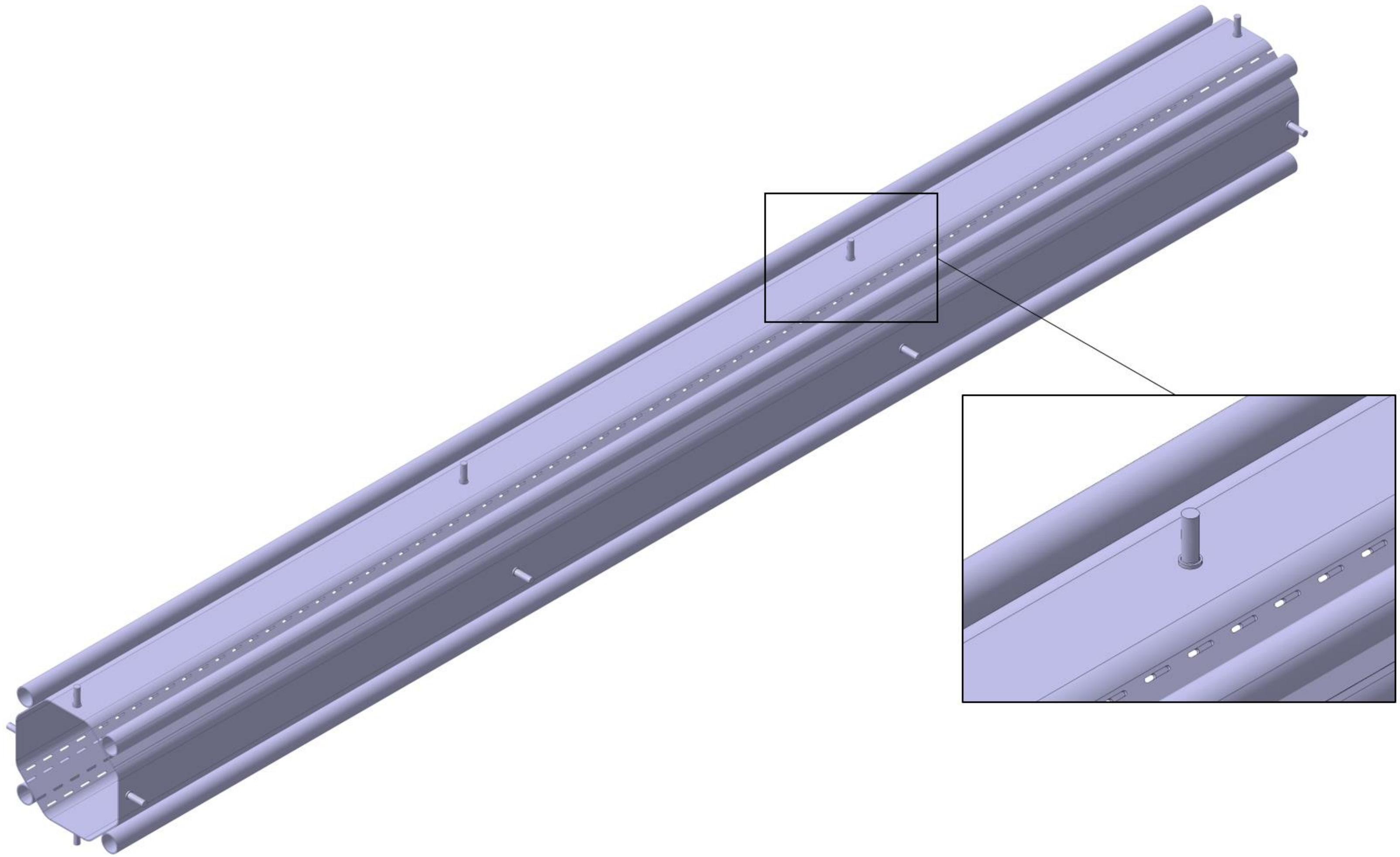
+/-45° cut

- More compact components (transversally)
- Longer absorber at the beam screen extremities
- Update of the interconnection module design

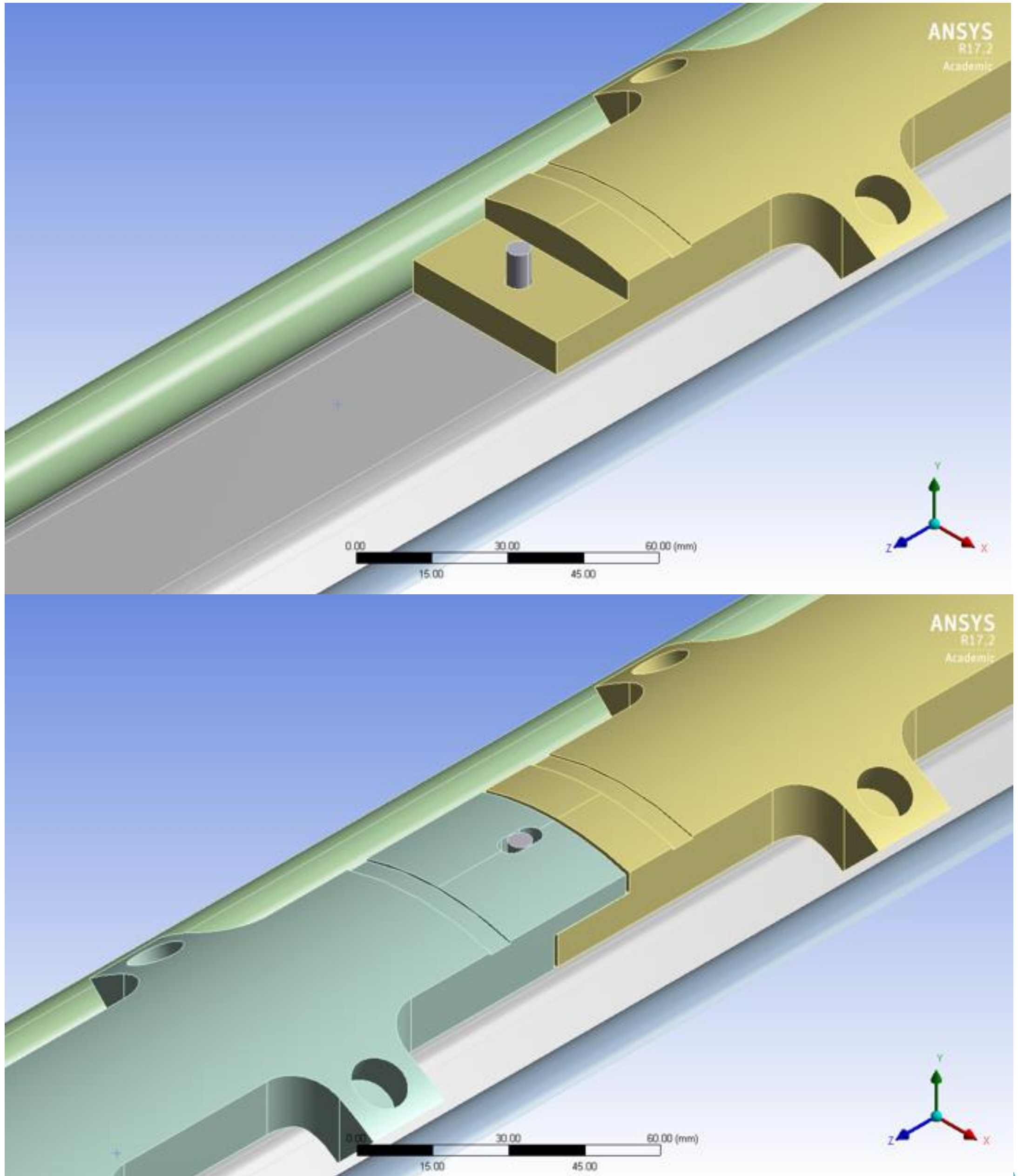
HiLumi HL-LHC PROJECT CERN

*BPM model provided by WP 13

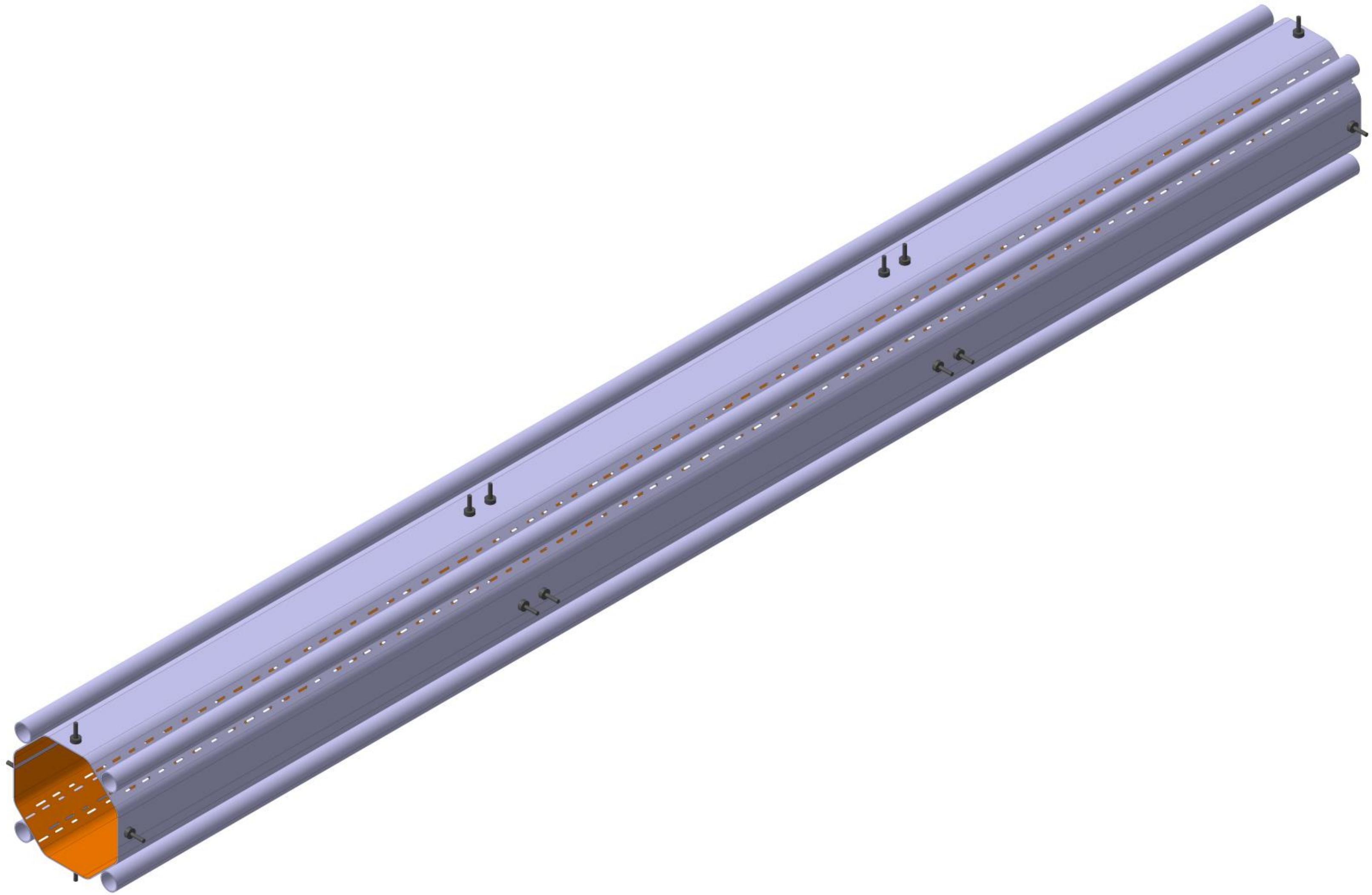
Old pins



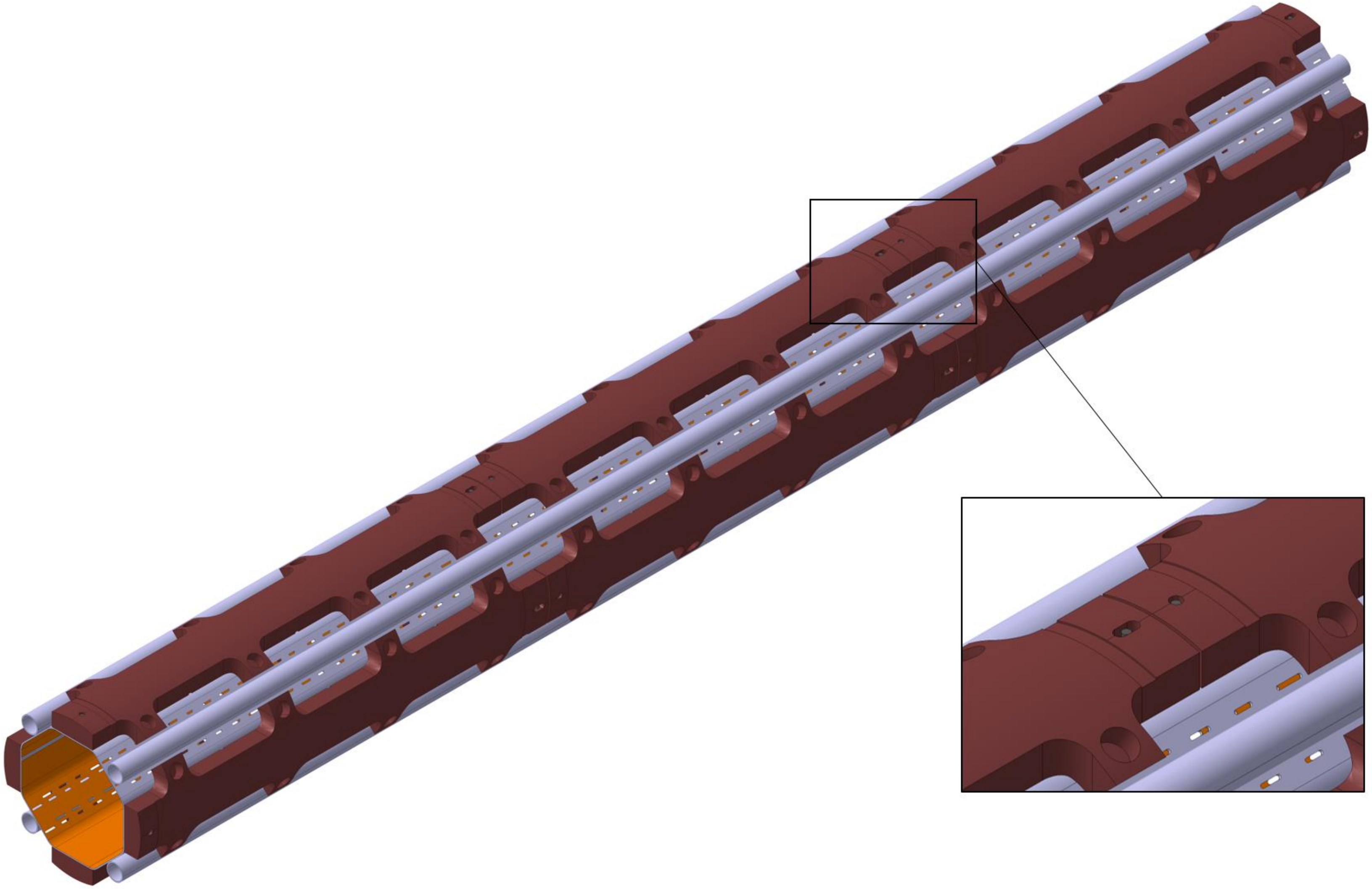
Old W blocks


ANSYS
R17.2
Academic
0.00
30.00
60.00 (mm)
15.00
45.00
Y
Z
X
ANSYS
R17.2
Academic
30.00
60.00 (mm)
15.00
45.00
Y
Z
X

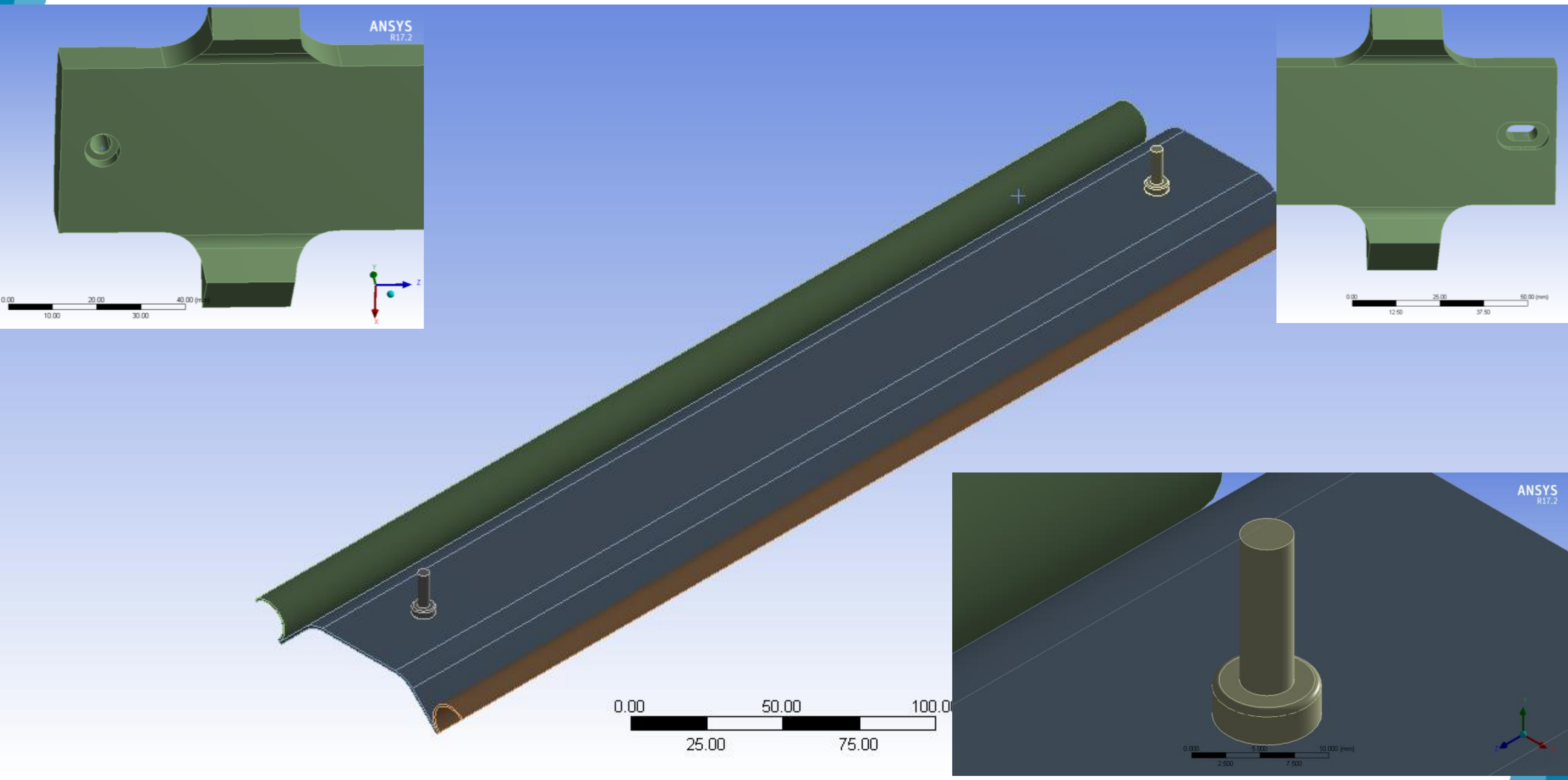
New pins



New W blocks



Details of the proposed beam screen design



Supporting system